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14. ABSTRACT

The objective is to further develop LAMP-QBEM, an efficient computational tool for the prediction of large amplitude ship motions and hydrodynamic loads. The key developments in this study include handling of complicated ship geometry and the development of a stable, accurate and efficient algorithm for free-surface time integration.

15. SUBJECT TERMS
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Contract Information

Contract Number	N00014-06-1-0137
Title of Research	Follow-on Effort of LAMP-QBEM Development: Large Amplitude Motion Program Using Quadratic Boundary Element Method
Principal Investigator	Dick K.P. Yue
Organization	Massachusetts Institute of Technology (MIT)

Technical Section

Technical Objectives

This is a joint effort between MIT and Science Application International Corporation (SAIC). The objective is to further develop LAMP-QBEM, an efficient computational tool for the prediction of large amplitude ship motions and hydrodynamic loads. The key developments in this study include handling of complicated ship geometry and the development of a stable, accurate and efficient algorithm for free-surface time integration. In addition, the LAMP-QBEM implementation is extended to the general body nonlinear (LAMP-4) approach and for body-linear hydrodynamics with large lateral motions.

Technical Approach

In CPM, Quadrilateral boundary elements are used. On each element, constant approximation for quantities is assumed. As a result, both geometry and physical quantities possess C^{-1} continuity on the boundary. CPM obtains a linear convergence rate with respect to panel size in general. But, it achieves no convergence at the intersection of mixed Dirichlet-Neumann boundaries if the boundary slopes.

In QBEM, a piecewise bi-quadratic representation of both the boundary and the unknowns on the boundary is adopted. Unlike in CPM, the boundary panels in QBEM are curvilinear quadrilaterals or (degenerate) curvilinear triangles with nine and seven nodes respectively where boundary positions and unknowns are specified/collocated. Geometry of elements and quantities on each element possess C^0 continuity at boundary edges. QBEM obtains quadratic convergence with the panel size even in the presence of free surface and body interactions with discontinuous slopes. Furthermore, boundary nodes at panel edges provide a robust treatment of boundary interactions. Significantly, for a given minimax (relative) error, QBEM is some two orders of magnitude more efficient than CPM for general applications.

Work Completed

- We developed the QBEM program and assisted SAIC in implementation of QBEM into the ship motion prediction program LAMP.

- We performed systematic validations of QBEM, and comparisons of convergence and robustness of QBEM vs. CPM.

- We investigated and improved the robustness and efficiency of QBEM for nonlinear ship motion predictions including

  - Treatment of multiple-surface intersections using the double-node technique
  - Treatment of incompatible (mortar) grids using independent collocation grids
  - Treatment of ship hulls with small holes or gaps between surfaces
  - Development of an effective algorithm for accurate velocity computation on ship hull and free surface.

- We performed a stability analysis for time integration and developed a stable, accurate and efficient scheme for time integration in LAMP-QBEM implementation

Results

The introduction of QBEM to a ship motion program like LAMP results in fundamental improvements in efficiency and robustness (relative to standard constant panel method, CPM).

Through systematic tests, we demonstrate the efficiency/accuracy of QBEM. For a problem with panel size h , QBEM obtains at least quadratic convergence with h, i.e., minimax error $\sim h^2$, everywhere. In contrast, CPM has only linear convergence with h in the interior of panel surfaces, slower than linear in general on panel surface boundaries, and generally fails to converge (minimax error $\sim O(1)$) at body/free-surface intersections. Thus QBEM is effectively $O(N)$ times faster than CPM, where N is the number of unknowns or panels (typically $N \sim O(10^{2\sim 3})$ or more for ship motion applications), for the same requisite average accuracy. As we go on to LAMP simulations with larger and larger N, QBEM is clearly superior to CPM in efficiency.

Significantly, QBEM results in a more robust application tool than CPM, improving LAMP in a number of key areas, many of which had been difficulty or impossible/impractical using CPM. These include: (a) the treatment of multiple-surface intersections; (b) calculation of spatial derivatives (such as velocities); (c) stability of time integration; and (d) implementation of nonlinear extensions to LAMP.

The MIT effort on this project has been to establish these properties of QBEM in the context of LAMP; to develop fundamental understanding and guidelines; and to provide essential modules and guidance to SAIC for integration into a new generation of LAMP based on QBEM. Significant performance gains of QBEM LAMP are expected in simulations of advanced ships with complex hull forms, in large problems requiring greater numbers of unknowns/panels; and in extensions to include (free-surface) nonlinearities. Specific demonstrations of these in real applications are underway at SAIC.

Impact/Application

The research is in conjunction with the effort of Dr. Woei-Min Lin, Ship Technology Division, Science Application International Corporation (SAIC), Annapolis. The developed ship motion prediction tool, LAMP-QBEM, will significantly advance the ship design capability of US Navy.

Publications

None

Student Graduated

None